March 23, 1965 R. E. SANSOM ET AL 3,175,106

INSPECTION APPARATUS

Filed Feb. 7, 1963

Fig. 1.

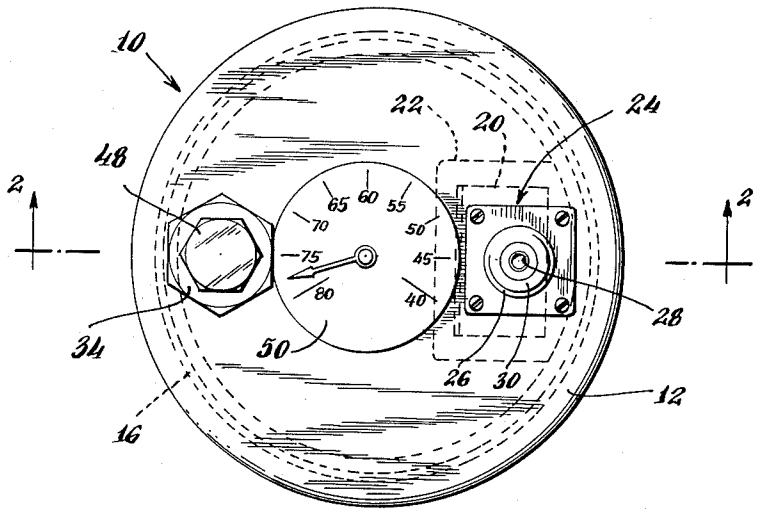
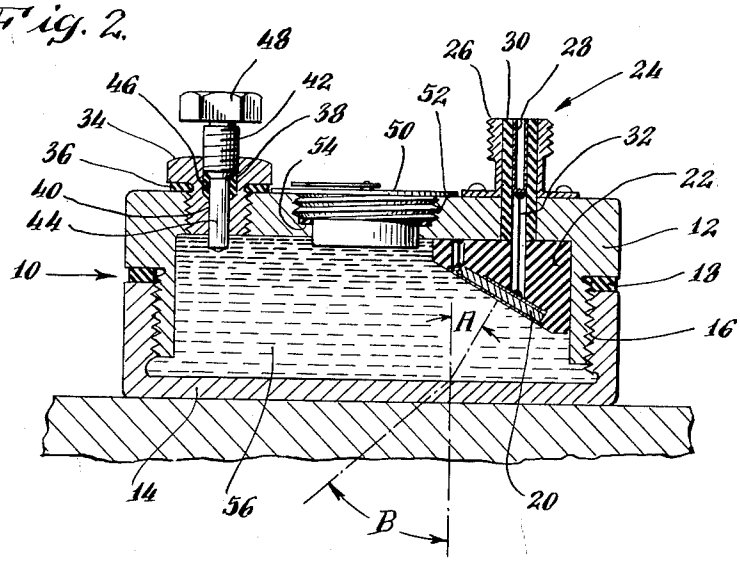


Fig. 2.



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INSPECTION APPARATUS

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This invention relates to the ultrasonic inspection of solid objects and, more particularly, to a novel search unit for use in such inspection.

Nondestructive testing by use of ultrasonic waves is a widely used method for the inspection of a variety of solid objects. In this technique, a suitable transducer, such as a piezoelectric crystal, is energized by high frequency electrical pulses and the resulting mechanical vibrations of ultrasonic frequency are directed into the object under test. Reflections from discontinuities in the object are then received by either the same or a similar transducer and are reconverted into electrical pulses for visual display or alarm purposes.

In practicing the technique of ultrasonic inspection, it is often desirable to vary the angle at which the ultrasonic beam enters the object under test. However, this is not easily accomplished, especially in non-immersion testing, as the ultrasonic vibrations will not travel satisfactorily through a gaseous medium such as air, but must be coupled to the tested object through a liquid medium. A number of attempts have been made to solve this problem and provide a variable angle transducer. However, in each of these devices a considerable amount of complexity and expense exists. Accordingly, it is the primary object of this invention to provide an improved variable angle search unit. Further objects are to provide such a search unit which is inexpensive, reliable, compact and maintenance-free.

The manner in which these objects are achieved will be more apparent from the following description, the appended claims and the figures of the attached drawing, wherein:

FIG. 1 is a plan view of a search unit constructed in accordance with our invention, and

FIG. 2 is a cross section taken along the line 2—2 of FIG. 1.

One of the basic principles of ultrasonics is that the ultrasonic wave follows the principles of Snell's law, which is widely known and widely used in optics. This law defines the relationship of the angles of incidence and refraction of a wave passing between two media having different indices of refraction. In formula form, the law may be written as follows:

$$\frac{\sin A}{\sin B} = \frac{V_1}{V_2}$$

Where A is the angle of incidence between the impinging beam and the normal to the surface, B is the angle between the emerging beam and the normal to the surface, V_1 is the velocity of sound in the first medium, and V_2 is the velocity of sound in the second medium.

Our invention makes novel use of Snell's Law by providing an ultrasonic transducer mounted at a fixed angle within a search unit comprising a liquid-filled container. We provide means for varying the pressure of the liquid medium, thereby varying the velocity of sound therethrough. When the search unit is placed against the surface of an object to be tested, variation of the pressure

on the liquid varies the velocity of sound transmission (V_1) and accordingly varies the angle of refraction (B) to maintain the relationship defined by Snell's Law.

By reference to the drawing, the search unit of this invention will be seen to comprise a cylindrical container **10** formed of a top member **12** and a closure cap **14** joined by means of threaded portion **16** and sealed by an annular gasket **18**. A piezoelectric crystal transducer **20** is mounted at an angle on a plastic block **22** which is suitably drilled to receive leads making electrical connections in the usual manner between the face and back of the crystal **20** to the case **10** and to a coaxial connector **24**. The outer element **26** of the coaxial connector **24** is connected directly to the container **10** to provide a grounding connection and internal conducting cylinder **28** receives the pin from the coaxial cable. A central insulator **30** extends through the case **10**, providing insulation for the wire **32**. A bushing **34** is threadedly inserted into a tapped hole in the top member **12** and sealing is provided by means of a flexible washer **36**. The bushing **34** includes an upper threaded bore **38** and a coaxial smooth bore **40** of smaller diameter which communicates with the interior of the chamber formed by members **12** and **14**. Into the threaded bore **38** is inserted the enlarged threaded portion **42** of an elongated pin **44** designed to fit snugly into bore **40**. A suitable resilient packing material **46** fills the space between bore **38** and pin **44** to prevent fluid leakage therethrough. The upper end of pin **44** carries a hexagonal head **48**. Also included in the top cap **12** is a pressure gauge **50** which may be of any suitable type, such as a Bourdon tube or a diaphragm type. The pressure gauge may be calibrated in terms of angle. The mounting of pressure gauge **50** is not critical and, for purposes of illustration, is shown in FIG. 2 as being effected by screwing into an internally threaded bore **52** in top cap **12**. Sealing is provided by means of a gasket **54** between cooperating shoulders of the gauge **50** and the cap **12**.

Any type of liquid **55** may be incorporated in the search unit of this invention. However, for best results, the liquid should be as incompressible as possible. This is because the operation of the invention depends for its success upon the variation of pressure within the liquid **54** achieved by the adjustment of pin **44**. Unless the liquid is relatively incompressible, too much longitudinal motion of the pin **44** is required, thus presenting a practical limitation. It has been discovered that water is a suitable medium for use in the present search unit. As is illustrated most clearly in FIG. 2, the crystal **20** is positioned at a fixed angle (A) relative to the face of the search unit. In one embodiment, for example, this has been set at 27° to the normal. As expressed in the above equation, the relationship between angles A and B is a function of the velocity of sound in the liquid and the solid medium. Accordingly, advancing or retracting pin **44**, thus varying the pressure within the liquid **55**, would cause a variation in angle B if angle A is held constant. It is assumed in this example that the material of both the object under test and the search unit container are of the same material (steel). However, this is not an important limitation and it is not necessary to the functioning of the device although some calibration correction of gauge **50** may be required. The following table indicates the manner in which the angle B varies with the change in pressure of the contained liquid **55**:

Table

[∠A=27°]

P.s.i.a.	V(water), cm.×10⁵/sec.	∠B (Shear waves)
14.7	1.481	90°
500	1.488	84
1,000	1.493	82.5
1,500	1.498	81
2,000	1.504	80
2,500	1.510	79
3,000	1.516	77.5
3,500	1.522	76.5
4,000	1.527	76
4,500	1.533	75
5,000	1.539	74.2

Only shear waves are shown in the above table. Surface waves are useful only at 90°. Also the longitudinal waves are so weak at these angles that they may be ignored.

It will be seen from this disclosure that the search unit of this invention is of a simple and reliable construction which has great utility in the ultrasonic inspection field. It will be apparent that a number of variations and modifications can be made in this invention without departing from the spirit and scope thereof. Accordingly, the foregoing description is intended to be illustrative only rather than limiting. This invention is limited only by the scope of the following claims.

What we clam as new and desire to secure by Letters Patent of the United States is:

1. An ultrasonic search unit which comprises: container means having at least a first surface arranged to be positioned against an object under test; a liquid substantially filling said container; ultrasonic transducer means arranged within said container means to project a beam of ultrasonic energy through said liquid and against said first surface at a preselected angle of incidence; and means for selectively varying the pressure of said liquid to vary the velocity of said ultrasonic energy therethrough.

2. The apparatus of claim 1 wherein said ultrasonic transducer means comprises a piezoelectric crystal.

3. The apparatus of claim 2 wherein said means for varying pressure comprises a threaded member arranged to be advanced into and withdrawn from said container.

4. An ultrasonic search unit which comprises: a first cup-shaped member having a first outer surface adapted to be positioned against an object under test; a second cup-shaped member detachably connected to said first member to define an enclosure therein; a piezoelectric crystal mounted within said enclosure to project ultrasonic energy against said first surface at a preselected angle of incidence; a liquid substantially filling said container; means for selectively varying the pressure of said liquid to vary the velocity of ultrasonic energy therethrough; and means for electrically energizing said piezoelectric crystal to generate said ultrasonic energy.

5. The apparatus of claim 4 wherein said first and second cup-shaped members are cylindrical.

6. The apparatus of claim 5 wherein said second member includes gauge means responsive to the pressure of said liquid.

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